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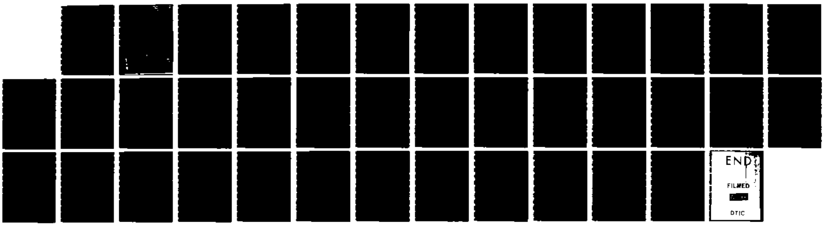

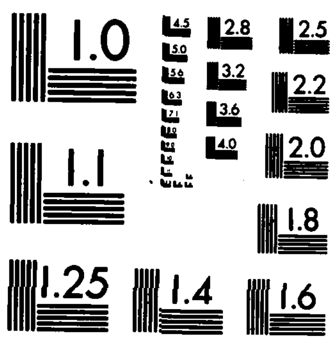

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Nonlinear Theory of the E × B Instability with an Inhomogeneous Electric Field

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Geophysical and Plasma Dynamics Branch
Plasma Physics Division

January 9, 1984

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Using analytical and numerical techniques, the nonlinear evolution of the E × B instability with an inhomogeneous electric field has been studied. For the case where the electric field component parallel to the density gradient is inhomogeneous, we find that the inhomogeneous E × B instability in the nonlinear regime (1) destabilizes short wavelength linear stable modes, (2) evolves into large scale anisotropic finger-like structures, (3) can be described by power laws, $P(k_x) \propto k_x^{-n_x}$, n_x (Continues)

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20. ABSTRACT (Continued)

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$\simeq 2$, $P(k_y) \propto k_y^{-n_y}$, $n_y \simeq 2$-3 where $P(k_x)$ and $P(k_y)$ are the one-dimensional power spectra parallel and perpendicular to the initial density gradient and (4) can be stabilized by quasilinear mechanisms in which the initial density gradient is modified by a finite amplitude wave spectrum. Applications are made both to naturally occurring small scale structures in the auroral ionosphere and striation formation in artificially produced ionospheric plasma clouds.

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CONTENTS

NONLINEAR THEORY OF THE E × B INSTABILITY WITH AN INHOMOGENEOUS ELECTRIC FIELD

1. INTRODUCTION

The E x B instability, also known as the gradient-drift instability, has been invoked to explain both natural and artificially induced plasma density structure and irregularities in the terrestrial ionosphere. This instability can be excited in a low pressure, weakly ionized, magnetized plasma that contains an ambient electric field orthogonal to both a magnetic field and a density gradient. The basic physical mechanism for the E x B instability [Linson and Workman, 1970; Perkins et al., 1973] is analogous to that describing the classical Rayleigh-Taylor instability in which a heavy fluid is supported by a lighter fluid. Originally applied by Simon [1963] and Hoh [1963] to laboratory gas discharges, this instability has been applied to ionospheric plasma cloud structuring [Haerendel et al., 1967; Linson and Workman, 1970; Völk and Haerendel, 1971; Perkins et al., 1973; Zabusky et al., 1973; Scannapieco et al., 1976; Ossakow et al., 1978; Chaturvedi and Ossakow, 1979; Keskinen et al., 1980; McDonald et al., 1981] and to the stability and transport of large scale convecting auroral ionospheric plasma enhancements [Keskinen and Ossakow, 1982, 1983; Vickrey et al., 1980]. However, these studies have addressed only the E x B instability driven by initial ambient homogeneous electric field. Perkins and Doles [1975] have shown, using linear theory, that sheared velocity flow (resulting from an initially self-consistent inhomogeneous electric field parallel to the density gradient) can stabilize the E x B instability in the collisional regime. Huba et al. [1983] verified numerically the results of Perkins and Doles [1975] and extended the linear theory of the E

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$\underline{B}$ instability with an inhomogeneous electric field to the collisionless regime. In order to properly apply the $\underline{E} \times \underline{B}$ instability to the auroral and polar ionosphere and magnetosphere one must consider the linear and nonlinear evolution of the $\underline{E} \times \underline{B}$ instability with an inhomogeneous electric field since it is well known that high latitude magnetospheric and ionospheric electric fields are usually inhomogeneous [see, for example, Fairfield, 1977 and references therein].

The purpose of this paper is to study the nonlinear evolution of the $\underline{E} \times \underline{B}$ instability with an inhomogeneous electric field. The organization of the paper is as follows. In Section 2 we give the general equations describing the $\underline{E} \times \underline{B}$ instability with an inhomogeneous electric field. In Section 3 we study the nonlinear evolution of the $\underline{E} \times \underline{B}$ instability with inhomogeneous electric field by numerically solving the fundamental fluid equations. In Section 4 we give a nonlinear analytic theory of the results in Section 3. Finally, in Section 5 we discuss and summarize our findings.

2. MODEL EQUATIONS AND LINEAR THEORY

The basic equations describing the evolution of the $\underline{E} \times \underline{B}$ instability in an inhomogeneous electric field are:

$$\frac{\partial N_\alpha}{\partial t} + \nabla \cdot (N_\alpha \underline{V}_\alpha) = 0 \quad (1)$$

$$-\frac{e}{m_e}\left(\underline{E} + c^{-1}\underline{V}_e \times \underline{B}\right) = 0 \quad (2)$$

$$\frac{e}{m_i}\left(\underline{E} + c^{-1}\underline{V}_i \times \underline{B}\right) - \nu_{in}\underline{V}_i = 0 \quad (3)$$

$$\nabla \cdot \underline{J} = \nabla \cdot N(\underline{V}_i - \underline{V}_e) = 0 \quad (4)$$

where α denotes species (α = e,i) and other symbols retain their conventional meaning.

The equilibrium configuration used in the analysis is shown in Fig. 1. The ambient magnetic and electric fields are in the z direction and the x,y plane, respectively, where $\underset{\sim}{B} = B_o \hat{\underline{z}}$ and $\underset{\sim}{E} = E_{ox}(x)\, \hat{\underline{x}} + E_{oy}\, \hat{\underline{y}}$. The electric field in the y direction is constant, while the electric field in the x direction is allowed to be a function of x. This gives rise to an inhomogeneous velocity flow in the y direction, i.e., $V_{oy}(x) = -cE_{ox}(x)/B$. The density is taken to be inhomogeneous in the x direction ($n_o = n_o(x)$) and temperature effects are ignored.

The basic assumptions used in the analysis are as follows. We assume that the perturbed quantities vary as $\delta f \sim \delta f(x) \exp[i(k_y y - \omega t)]$, where k_y is the wave number along y direction and $\omega = \omega_r + i\gamma$, implying growth for $\gamma > 0$. The ordering in the frequencies is such that $\omega \ll \Omega_i$ and $\nu_{in} \ll \Omega_i$ (F region approximation), where ν_{in} is the ion-neutral collision fre-quency and Ω_i is the ion gyrofrequency. We ignore finite gyroradius effects by limiting the wavelength domain to $kr_{Li} \ll 1$, where r_{Li} is the mean ion Larmor radius. We neglect perturbations along the magnetic field $(k_\parallel = 0)$ so that only the two-dimensional structure in the x,y plane is obtained.

Solving Eq. (2) and (3) for $\underline{V}_e$ and $\underline{V}_i$, substituting into (1) (for electrons) and (4) we find [Perkins and Doles, 1975]

$$\frac{\partial N}{\partial t} + \underline{V}_{oy} \cdot \nabla N - \frac{c}{B} \nabla \delta\phi \times \hat{\underline{z}} \cdot \nabla N = 0 \tag{5}$$

$$\nabla \cdot N \nabla \delta\phi = - E_{oy} \frac{\partial N}{\partial y} - \frac{\partial}{\partial x} \left(E_{ox}(x) N \right) \tag{6}$$

where we have transformed to a frame moving with velocity $\underline{V}_o = -\frac{c}{B} E_{oy}\,\hat{\underline{x}}$, let $N = n_o(x) + \delta n$, $\underline{E} = E_{ox}(x)\hat{\underline{x}} + E_{oy}\,\hat{\underline{y}} - \nabla\delta\phi$, and $\underline{V}_{oy}(x) = -\,cE_{ox}(x)/B\,\hat{\underline{y}}$. A relationship between initial equilibrium $n_o(x)$ and $E_{ox}(x)$ can be found by assuming $\nabla\cdot\underline{J} = 0$ from Eq. (4) or (6) which gives

$$n_o(x)E_{ox}(x) = cst. \tag{7}$$

where we take the constant to be the left hand side of Eq. (7) evaluated at $x = -\infty$. Adopting a Fourier representation in Eq. (5), (6) for δn, $\delta\phi$, eliminating δn from Eq. (6) using Eq. (5) we find the dispersion relation

$$\frac{\partial^2 \delta\phi_{\underline{k}}}{\partial x^2} + A(k_y,\ x,\ \omega)\,\frac{\partial \delta\phi_{\underline{k}}}{\partial x} + B(k_y,\ x,\ \omega)\,\delta\phi_{\underline{k}} = 0 \tag{8}$$

where

$$A(k_y,x,\omega) = \frac{1}{n_o}\frac{dn_o}{dx}\left[1 + k_yV_{oy}(x)(\omega - k_yV_{oy})^{-1}\right]$$

$$B(k_y,x,\omega) = -\,k_y^2 + i\,k_y\left(\frac{cE_{oy}}{B}\right)k_y\,\frac{1}{n_o}\frac{dn_o}{dx}\,(\omega - k_yV_{oy})^{-1}$$

$$+\,k_yV_{oy}(\omega - k_yV_{oy})^{-1}\left[\frac{1}{n_o}\frac{d^2n_o}{dx^2} - k_y\,\frac{1}{n_o}\frac{dn_o}{dx}\frac{dV_{oy}}{dx}\,(\omega - k_yV_{oy})^{-1}\right]$$

Perkins and Doles (1975) expand Eq. (8) about $x = x_o$ where x_o is the position of maximum n_o'/n_o by taking ($f' \equiv df/dx$)

$$n_o'/n_o = \left[1-(x-x_o)^2/D^2\right]/L_n \tag{9}$$

Assuming $k_y^2 L_n^2 \gg 1$ and $k_y^2 D^2 \ll 1$, and by making several variable changes, they solve Eq. (8) analytically. The important conclusion of their results is that the $\underline{E} \times \underline{B}$ instability is stabilized, in the linear regime, when

$$\frac{E_x(x_o)}{E_y} > \frac{2}{k_y D} \tag{10}$$

Thus, the influence of velocity shear, i.e., an inhomogeneous E_{ox}, is to preferentially stabilize the short wavelength modes, i.e., those with $k_y D \gg 1$. Huba et al. [1983] verified Eq. (10) by solving numerically the fully nonlocal equation (8).

To recover the local theory limit we let $\frac{\partial}{\partial x} \rightarrow ik_x$ and assume $k_x^2 L_N^2 \gg 1$ and $k_y^2 L_N^2 \gg 1$ where $L_N = \left(n_o'/n_o\right)^{-1}$ is the scale length of the density inhomogeneity evaluated at $x = x_o$. For simplicity we also take $\underline{E} = E_{ox}\,\hat{\underline{x}} + E_{oy}\,\hat{\underline{y}} =$ constant. Following standard techniques, we find for the frequency and growth rate

$$\omega_r = k_y V_{oy} \tag{11}$$

$$\gamma = \frac{k_y}{k} \frac{\left(\underline{k} \cdot \frac{c}{B} \underline{E}\right)}{kL_N} \tag{12}$$

the usual $\underline{E} \times \underline{B}$ instability growth rate [Linson and Workman, 1970] in the collisional limit.

3. NONLINEAR EVOLUTION

Since the $\underline{E} \times \underline{B}$ instability becomes highly nonlinear and analytically intractable we will study the nonlinear evolution of the $\underline{E} \times \underline{B}$ instability in an inhomogeneous electric field by numerically solving the fundamental equations (5) and (6). We choose parameters typical of naturally occurring high latitude convecting ionospheric plasma enhancements [Vickrey et al., 1980] and artificially produced ionospheric plasma clouds [McDonald et al., 1981]. Equations (5) and (6) were solved on a numerical grid consisting of 258 grid points in the x-direction and 102 grid points in the y-direction with constand grid spacing of 0.3 km in the x-direction and 0.2 km in the y-direction. As a result, the simulation plane has an x,y extent of 80 and 20 km, respectively. The plasma density N in equation (5) was advanced in time using a multi-dimensional flux-corrected variable timestep leapfrog-trapezoid scheme [Zalesak, 1979] which is second order in time and fourth order in space. At each timestep the self-consistent electrostatic potential $\delta\phi$ of the plasma enhancement in Eq. (6) was deter-mined using a Chebychev iterative method [McDonald, 1980] with a convergence criterion of 10^{-4}. Periodic boundary conditions were imposed in the y-direction with Neumann boundary conditions ($\partial/\partial x = 0$) in the x-direction. A slab approximation is used to model the zeroth order plasma density with profile given by $n_o(x) = N_o \{1 + 4.5[\tanh(x-x_1)/L_N + \tanh(x_2-x)/L_N]\} \{1 + \varepsilon(x,y)\}$ with $x_1 = 10$ km, $x_2 = 35$ km, and $L_N = 10$ km. This gives a maximum plasma density to background ratio of approximately 10. The initial perturbation in taken to be completely random with root-mean-square amplitude of 10^{-4}.

The ambient electric field is chosen to be

$$\underset{\sim}{E}_o(x) = E_{ox}(x)\, \hat{\underline{x}} + E_{oy}\, \hat{\underline{y}} \tag{13}$$

where

$$\underset{\sim}{E}_o(x = -\infty) = E_o \sin\vartheta\, \hat{\underline{x}} + E_o \cos\vartheta\, \hat{\underline{y}} \tag{14}$$

so that $\vartheta = \tan^{-1}(E_{ox}/E_{oy})$ at $x = -\infty$. The influence of the x component of the electric field is then studied by varying ϑ, the angle between $\underset{\sim}{E}$ and $\hat{\underline{y}}$ at $x = -\infty$. The form of $E_{ox}(x)$ considered in the analysis is:

$$E_{ox}(x) = E_o \sin\vartheta\left(N_o/n_o(x)\right) \neq \text{constant} \tag{15}$$

We comment that Eq. (15) is an equilibrium solution which satisfies $\nabla \cdot \underline{J} = 0$ i.e., Eq. (4) or (6).

We consider two models with different initial electric field configurations to illustrate the effect of an inhomogeneous electric field. Model 1 has $E_{oy} = 10$ mV/m, $E_{ox} = 0$ (no velocity shear) while Model 2 takes $E_{ox}(-\infty) = 8.6$ mV/m and $E_{oy} = 5$ mV/m giving $\vartheta \simeq 60^o$. These electric field magnitudes are chosen to be typical of the high latitude diffuse auroral F-region ionosphere [Vickrey et al., 1980]. Figure 2a-2d shows the evolutions of the $\underline{E} \times \underline{B}$ instability using Model 1 (no velocity shear). Figure 2a shows the initial configuration which includes the small random perturbation. Figure 2b illustrates the linear regime at $t = 250$ sec ($\gamma t \simeq 5$) and shows unstable growth on the trailing side of the plasma enhancement as predicted by the linear result given by Eq. (12). One can

note the depletion jetting to the front side of the enhancement in analogy to the initial evolution of the $\underline{E} \times \underline{B}$ gradient drift instability in artificial ionospheric plasma clouds [Zabusky et al., 1973; Scannapieco et al., 1976]. Figure 2c gives the structure of the plasma enhancement at t = 500 sec and shows steepened fingers which are beginning to elongate. Finally Figure 2d displays the plasma enhancement at t = 650 sec in the fully nonlinear regime. The trailing edges of the principal fingers (striations) have steepened, become quasi-one dimensional and bifurcated. The length scales on Figure 2a-d are distorted with the depletions longer and narrower than is depicted.

Figure 3a-d give sample one-dimensional spatial power spectra at t = 0, 250, 650 sec Model 1. These power spectra are defined as follows

$$P(k_x) = \int dk_y \, \overline{P}(k_x,k_y)$$

$$P(k_y) = \int dk_x \, \overline{P}(k_x,k_y)$$

where $\overline{P}(k_x,k_y) \equiv (L_x L_y)^{-1} [\delta n(k_x,k_y)/N_o]^2$ is the spectral density, $\delta n = N-N_o$ with N_o the peak plasma enhancement density, and $L_x L_y$ is the area of the numerical simulation plane. Figure 3a illustrates the power spectrum $(P(k_y)$ of the random perturbation used to initialize the $\underline{E} \times \underline{B}$ instability. Figure 3b shows the power spectrum $P(k_y)$ in the linear stage of the instability and compares favorably with the growth rate vs. k_y from local theory [Huba et al., 1983]. Figure 3c-3d gives the power spectra in the x- and y-directions, respectively, in the nonlinear regime at t = 650

sec. For both cases these power spectra are well-fitted with an inverse power law with spectral index $n_x \approx 2$ for $2\pi/k_x$ between approximately 30 and 1 km and $n_y \approx 2-2.5$ for $2\pi/k_y$ between 20 and 1 km.

Figures 4a-4d illustrate the evolution of the $\underline{E} \times \underline{B}$ instability with an inhomogeneous electric field using Model 2. Figure 4a gives the initial configuration which is identical to Fig. 2a. Figure 4b shows the isodensity contours of the plasma enhancement in the linear regime at t = 700 sec ($\gamma t \approx 5$). Figure 4c gives the evolution at t = 900 sec and shows a distinct bending of the striations. Figure 4d details the $\underline{E} \times \underline{B}$ instability in the nonlinear regime at t = 1250 sec where one notes that the fingers (striations) are no longer primarily aligned with the flow. Similar morphologies are also observed for other velocity shears ($\theta = 30^o$).

Figures 5a-5c give sample power spectra for Model 2 in the linear and nonlinear regime at t = 425 and 1250 sec, respectively. Figure 5a illustrates the linear regime, shows the suppression of the shorter wavelength fluctuations in agreement with linear theory, eq. (10), [Perkins and Doles, 1975; Huba et al., 1983], and indicates a preferred scale size. Figure 5b gives a sample power spectrum in the y-direction, $P(k_y)$, and can be described by a power law $P(k_y) \sim k_y^{-n_y}$, $n_y \approx 2-2.5$ in approximate agreement with the no shear case Model 1. The power spectrum in the x-direction $P(k_x)$ in the nonlinear regime is given in Fig. 5c and can also be described by a power law $P(k_x) \sim k_x^{-n_x}$, $n_x \approx 2$. Similar power laws and spectral indices are also observed for the case where $\theta = 30^o$.

Figure 6 shows the evolution of the mean density profile along the x-axis (averaged over the y-direction) at t = 0, 700, 950 sec during the linear unstable stage of Model 2. Similar result are found for the case

$\vartheta = 30^o$. We show in the next section that this relaxation is responsible, in part, for the stabilization of the fastest growing linear modes.

4. QUASILINEAR THEORY

We present arguments for a quasilinear stabilization mechanism for the $\underline{E} \times \underline{B}$ instability with an inhomogeneous electric field. We show that the mean density gradient driving the instability is modified by an unstable spectrum of waves of finite amplitude. By dividing $N = n_o + \delta n$, $\underline{V}_e = \underline{V}_{eo} + \delta \underline{V}_e$, $\langle \delta n \rangle = \langle \delta V_e \rangle = 0$, into mean and oscillating parts (with $\langle\ \rangle$ denoting space and time average), the electron continuity equation (1) can be written

$$\frac{\partial n_o}{\partial t} = \frac{\partial \langle N \rangle}{\partial t} = -\nabla \cdot \langle \delta n\ \delta \underline{V}_e \rangle \tag{16}$$

$$\frac{\partial \delta n}{\partial t} + n_o \nabla \cdot \delta \underline{V}_e + \delta n \nabla \cdot \underline{V}_{eo} + \underline{V}_{eo} \cdot \nabla \delta n + \delta \underline{V}_e \cdot \nabla n_o$$

$$= \nabla \cdot \langle \delta n\ \delta \underline{V}_e \rangle - \nabla \cdot \delta n\ \delta \underline{V}_e \tag{17}$$

with $\langle \delta n\ \delta \underline{V}_e \rangle = (L_y)^{-1} \int d\underline{y}\ \delta n\ \delta \underline{V}_e = (L_y)^{-1} \int \frac{d\underline{k}_y}{(2\pi)^{-3}} \delta V_{e,-\underline{k}_y} \delta n_{\underline{k}_y}$ and $\delta \underline{V}_e \cong -\frac{c}{B} \nabla \delta \phi \times \hat{z}$ and L_y is the length of the system in the y-direction. To find $\partial n_o / \partial t$ in Eq. (16) to lowest (quadratic) order in $\delta \phi$ one needs to compute δn to linear order in $\delta \phi$ using Eq. (17) which gives:

$$\delta n_{\underline{k}_y}(x) = -\frac{c}{B} k_y \frac{\partial n_o}{\partial x} \left[\omega - k_y V_{ey}(x)\right]^{-1} \delta \phi_{\underline{k}_y}(x) \tag{18}$$

giving

$$\langle \delta n \, \delta \underline{V}_e \rangle = (L_y)^{-1} \frac{ic}{B} \underline{k}_y \times \hat{z} \int \frac{dk_y}{(2\pi)^3} \delta\phi_{-\underline{k}_y} \delta n_{\underline{k}_y}$$

with $\delta n_{\underline{k}_y}$ given by (18). Inserting into (16) we find

$$\frac{\partial n_o}{\partial t} = - \frac{\partial}{\partial x} D(x) \frac{\partial}{\partial x} n_o \qquad (19)$$

with $D(x) = \mathrm{Re} \left[i \frac{c^2}{B^2} \int dk_y \frac{k_y^2 I_{\underline{k}_y}(t)}{\omega - k_y V_{eo}(x)} \right]$

$$\simeq \frac{c^2}{B^2} \int dk_y \frac{I_{\underline{k}_y}(t)}{[\omega_r - kV_{eo}(x)]^2 + \gamma_k^2} \qquad (20)$$

where $\omega = \omega_r + i\gamma$ has been used. The spectral energy density $I_{\underline{k}_y}(t) \equiv L_y^{-1} |\delta\phi_{\underline{k}_y}(t)|^2$ changes with time according to

$$\frac{\partial I_{\underline{k}_y}(t)}{\partial t} = 2\gamma_{\underline{k}}(t) I_{\underline{k}_y}(t) \qquad (21)$$

Equation (19)-(21) provide a description of the quasilinear evolution of the $\underline{E} \times \underline{B}$ instability with an inhomogeneous electric field.

Assuming weakly growing modes, i.e., $\gamma_k^2 \ll |\omega_r - kV_{eo}(x)|^2$ the diffusion can be approximated by

$$D(x) \simeq \frac{c^2}{B^2} \int dk_y \, \gamma_{\underline{k}_y}^{-1} k_y^2 I_{\underline{k}_y}(t). \qquad (22)$$

From the work of Huba et al. [1983] and the previous numerical simulation

results we observe that, although $\gamma_{\underline{k}_y}$ maximizes for preferred scale size given by $k_yL \sim O(1)$, the distribution of γ vs. k_y is broad. As a result, we take $\gamma_{\underline{k}_y}$ to be of the form

$$\gamma_{\underline{k}_y}(t) = \gamma_o(t)\exp[-(k_y - k_o)^2/k_w^2]$$

In addition, we assume

$$I_{\underline{k}_y}(t) = I_o(t)\exp[-(k_y - k_o)^2/k_w^2]$$

where $\gamma_o \simeq \zeta V_o/L$, $k_o \simeq \eta L^{-1}$, and k_w is the mean width of the distribution with $k_w \gtrsim k_o$. Here, ζ,η are constants of order unity [Huba et al., 1983. Inserting these expressions for $\gamma_{\underline{k}_y}$ and $I_{\underline{k}_y}$ into eq. (22) we take

$$D(x) \simeq \frac{c^2}{B^2}\gamma_o^{-1} I_o \int_{k_o - \frac{k_w}{2}}^{k_o + \frac{k_w}{2}} dk_y k_y^2$$

$$\simeq \frac{c^2}{B^2}\frac{L}{\zeta V_o} I_o \frac{k_w^3}{12} \tag{23}$$

For approximate nonlinear saturation of the fastest growing mode with wavenumber k_{max} we have

$$\gamma = \gamma_L - Dk_{max}^2 = 0 \tag{24}$$

Using eq. (23) in (24) we find

$$\left(\frac{\delta\phi}{\phi_o}\right)_{k=k_{max}} \simeq \frac{\sqrt{12}\ \zeta}{(k_{max}L)}\frac{1}{(k_wL)} \tag{25}$$

where $\phi_o = (BV_oL/c)$. From Huba et al. [1983], $\zeta \simeq 0.2$, $k_{max}L \simeq 1$, $k_wL \simeq 5$, which gives $\delta\phi/\phi_o \sim 0.11$ which is not inconsistent with the previous numerical simulation results in Sec. 3. After the initial mean density gradient has relaxed to a certain degree, small scale modes ($kL \gg 1$) can become unstable leading to two-dimensional wave coupling processes which will determine the wave spectrum.

5. DISCUSSION AND SUMMARY

We have studied, using analytical and numerical techniques, the nonlinear evolution of the $\underline{E} \times \underline{B}$ instability with an inhomogeneous electric field. The principal results of this study are as follows:

1. The basic morphology and power spectra of the $\underline{E} \times \underline{B}$ instability with an inhomogeneous electric field in the nonlinear regime is similar to homogeneous (no shear) case.
2. Nonlinear effects destabilize the linearly stable modes associated with the $\underline{E} \times \underline{B}$ instability with inhomogeneous electric field.
3. Quasilinear mechanisms, in which the initial density gradient driving the inhomogeneous $\underline{E} \times \underline{B}$ instability is modified by a finite amplitude wave spectrum, can contribute to nonlinear stabilization.

Recently, large scale equatorward convecting plasma enhancements in the diffuse auroral F-region ionosphere have been identified and studied [Vickrey et al., 1980] using both radar and satellite measurements. Observed in regions of diffuse auroral particle precipitation and associated field aligned currents, these enhancements have overall latitudinal dimensions of a few hundred kilometers, contain relatively

steep poleward and equatorward edges, and have been shown to be approximately field-aligned resembling vertical slabs of ionization. Their occurrence, which is maximized in the evening-midnight sector, is apparently not strongly related to magnetic activity nor to E-region processes. The presence of plasma density irregularities associated with these enhancements has been verified using satellite scintillation studies [Fremouw et al., 1977; Rino et al., 1978; Vickrey et al., 1980]. The scintillation data have indicated that the electron density irregularities are structured like L-shell aligned sheets for irregularity scale sizes of approximately 1 km [Fremouw et al., 1977; Rino et al., 1980]. Moreover, the source region of these scintillation causing irregularities has been demonstrated to be latitude limited [Rino and Owen, 1980] and contained in a vertical slab of F region plasma. Keskinen and Ossakow [1982, 1983] showed that these convecting plasma enhancements can be destabilized by the $\underline{E} \times \underline{B}$ instability. Their results, using a homogeneous electric field, were not inconsistent with available experimental observations [Rino et al., 1978; Vickrey et al., 1980; Tsunoda and Vickrey, 1982]. The results of the present study, with an inhomogeneous electric field, may help explain the geometric (L-shell alignment) nature of these structures if one assumes the east-west (north-south) direction corresponds to the y(x)-axis. In this case, the fingerlike structures in the nonlinear regime of Model 2 would be approximately east-west or L-shell aligned.

These results are also applicable to the development of the $\underline{E} \times \underline{B}$ instability in artificially injected ionospheric plasma (barium) cloud releases. By including a self-consistent inhomogeneous electric field, we note that the time scales for striation formation and jetting is increased

compared to the homogeneous case. This effect will lead to an increase in striation onset time [McDonald et al., 1981]. However, in the nonlinear regime, our studies with an inhomogeneous electric field show similar morphologies and power spectra with respect to the homogeneous case.

Acknowledgments

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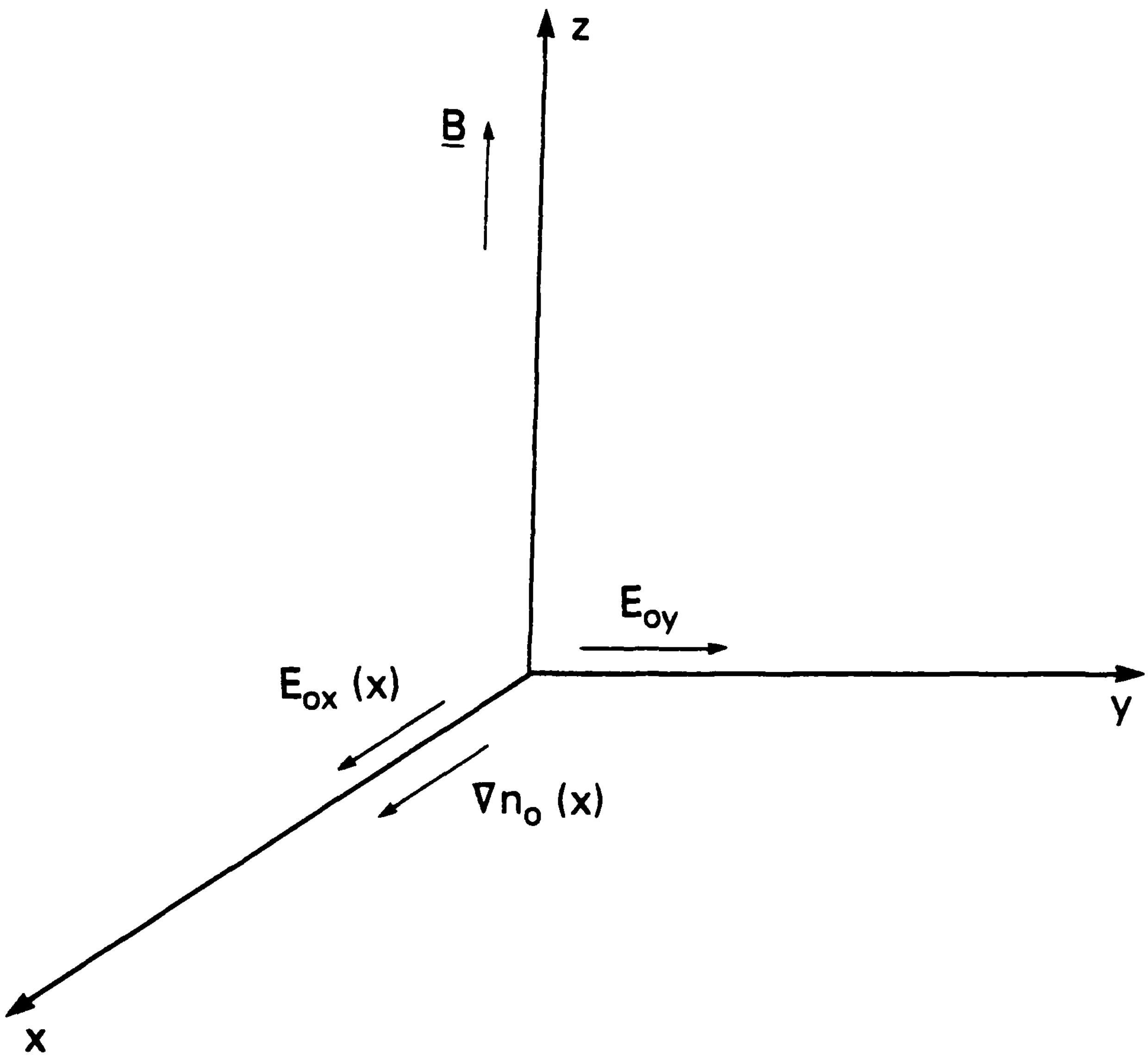

Fig. 1 — Basic geometry and coordinate system used in this analysis.

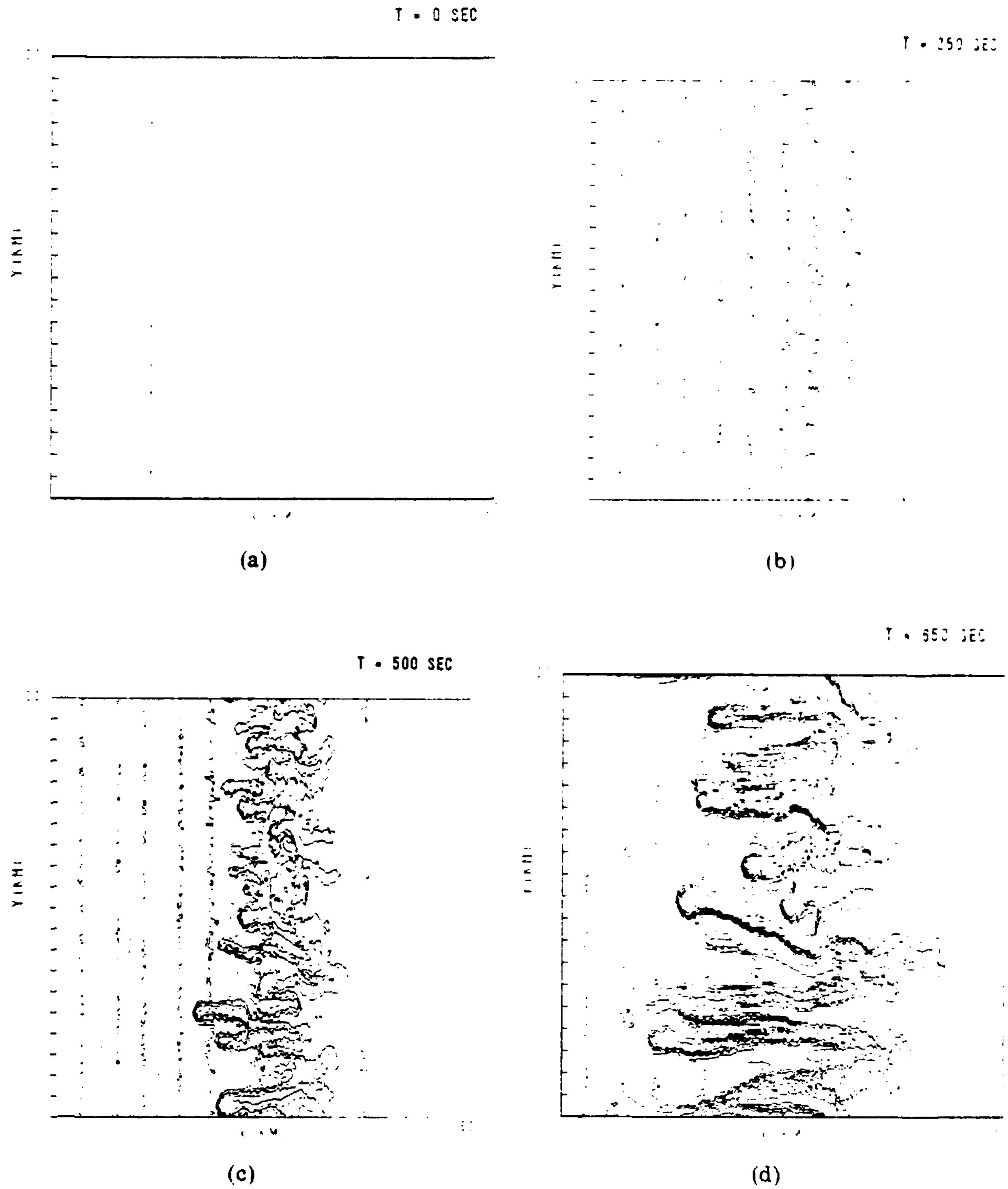

Fig. 2 — Real space isodensity contour plots of $n(x,y)/N_0$ for model 1 at (a) t = 0 sec, (b) t = 250 sec, (c) t = 500 sec, (d) t = 650 sec. The x-axis is compressed by a factor of 2.58. The distance between tic marks in the x-direction (y-direction) is 5 km (12.8 km). Eight contours are plotted in equal increments of 1.25 beginning at 1.25. The observer is looking downward along the magnetic field lines.

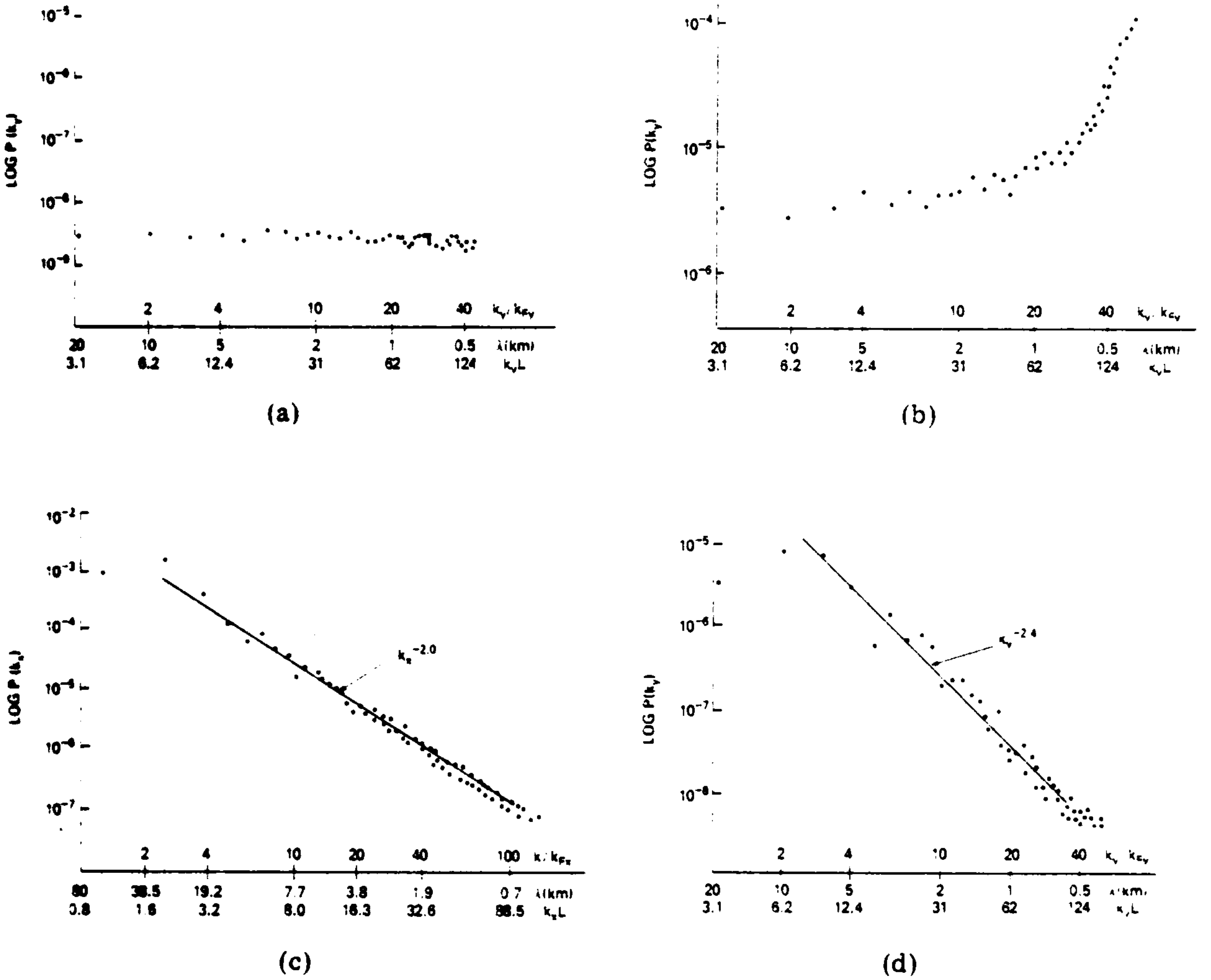

Fig. 3 — Sample one-dimensional power spectra for model 1 at (a) t = 0 sec, $P(k_y)$ (b) t = 250 sec, $P(k_y)$ (c) t = 650 sec, $P(k_x)$ (d) t = 650 sec, $P(k_y)$. Here $k_{Fx} = 2\pi/80$ km^{-1} and $k_{Fy} = 2\pi/20$ km^{-1}, the solid curve is a least squares fit to modes 2-80 in the x-direction and to modes 2-30 in the y-direction. The units of $P(k_x)$, $P(k_y)$ are km.

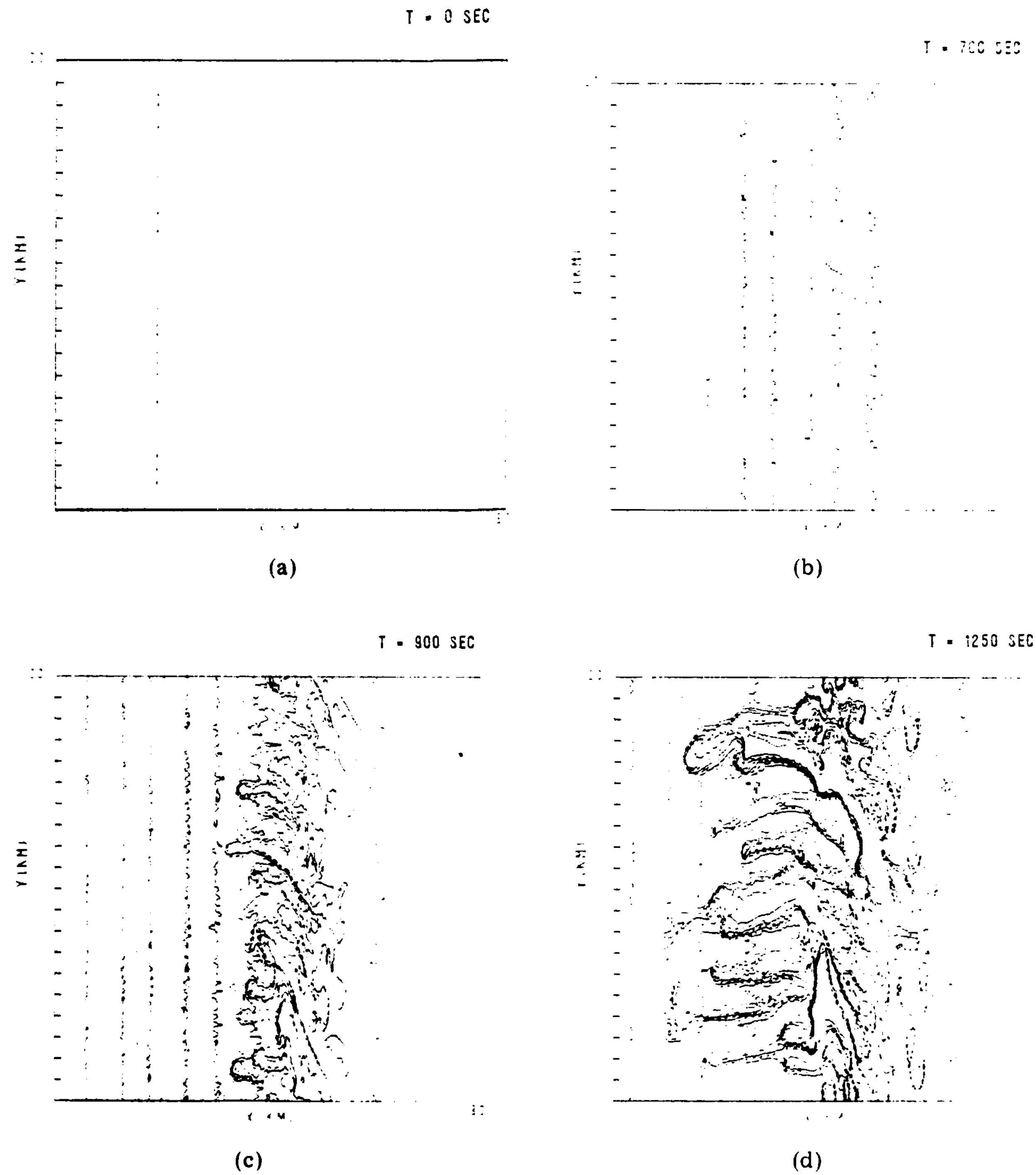

Fig. 4 — Real space isodensity contour plot of $n(x,y)/N_0$ for model 2 at (a) t = 0 sec, (b) t = 700 sec, (c) t = 900 sec, (d) t = 1250 sec, using the same format as Figure 2.

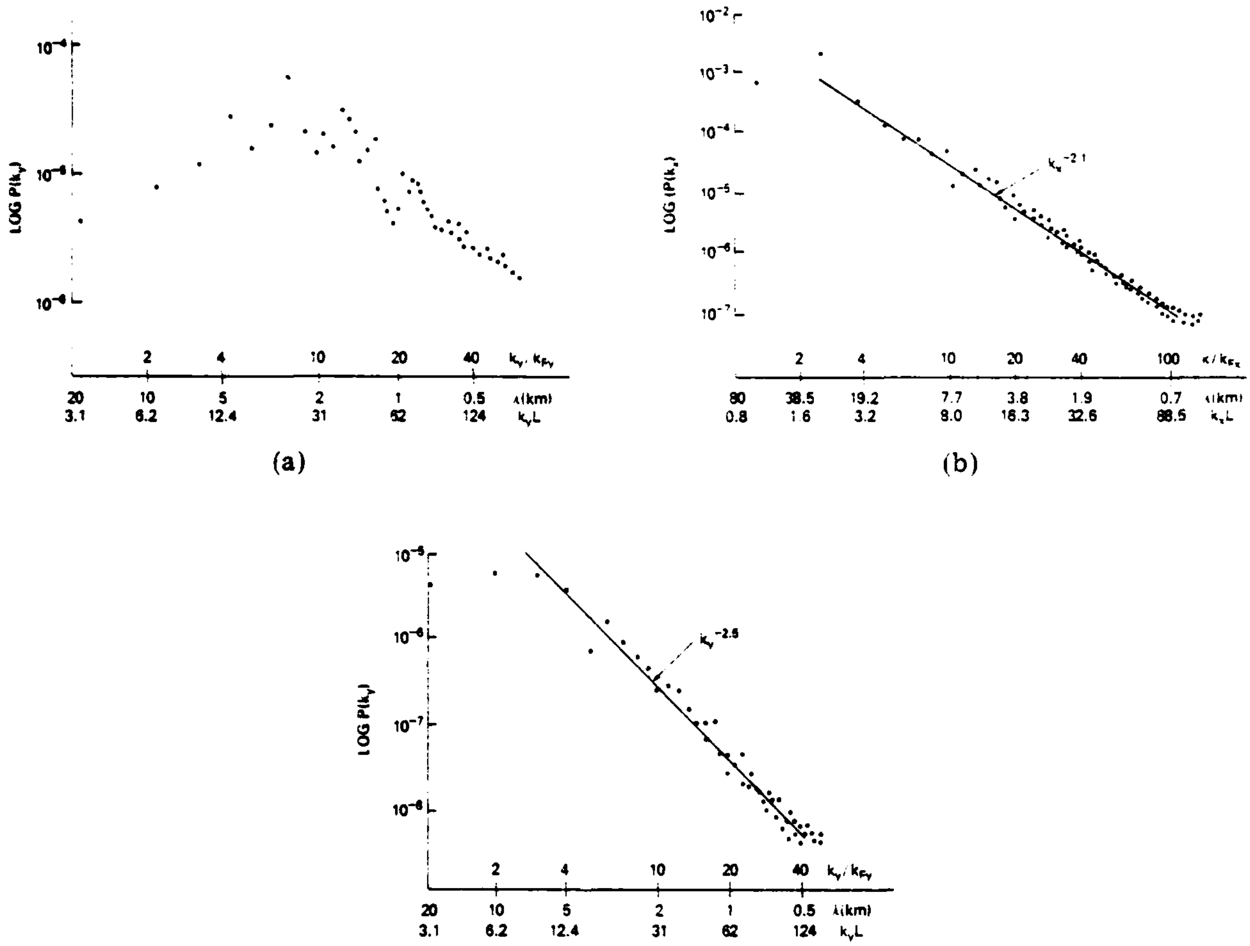

Fig. 5 — Sample one-dimensional power spectra for model 2 at (a) t = 425 sec, (b) t = 1250 sec, (c) t = 1250 sec in same format as Figure 3.

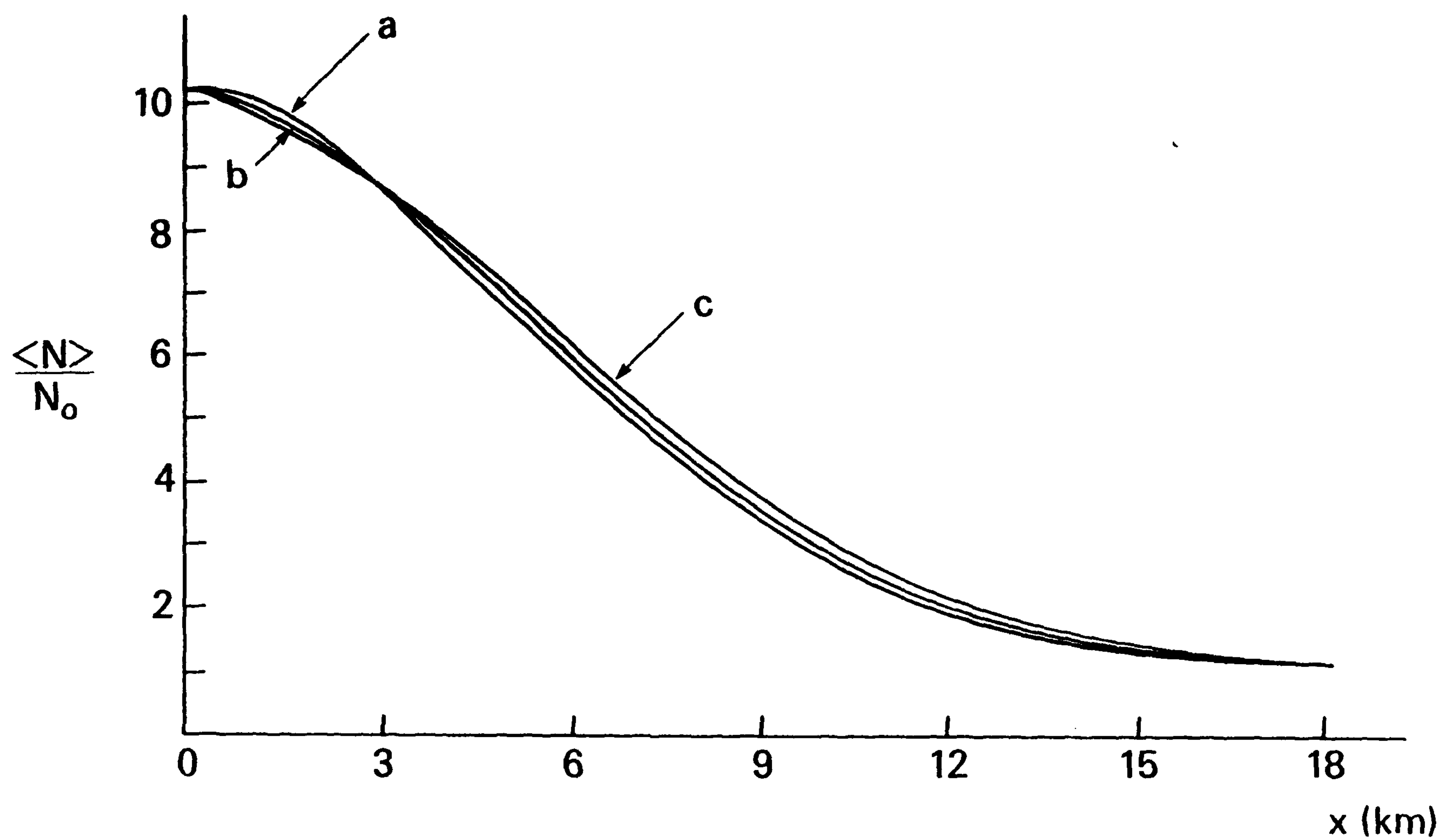

Fig. 6 — Mean density profiles along x-axis (averaged over y-axis) at several different times in the linear unstable stage of Model 2. Curve a,b,c correspond to $t = 700, 950$ sec. Distance x is measured from the maximum plasma enhancement density.

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